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HEAT-ACTIVATED ALARM SYSTEM FOR RAILROAD BOXCARS CARRYING EXPLO--ETC(U)  
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## CIVIL ENGINEERING LABORATORY

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## INTRODUCTION

Accident records of railroad boxcars carrying explosive materials clearly demonstrate the need for an early warning alarm system. Physical evidence and experience suggest that these accidents were most likely related to local overheating of the boxcar. CEL was tasked by the Naval Facilities Engineering Command to develop an early warning heat alarm system.

This project consisted of two parts: concept development and hardware development. The former was involved with the organization of the overall effort, the identification of the problem area and its requirements, and the development of design criteria and system concept. The latter part was concerned with the assembly and test of the system hardware based on the developed criteria. This report covers both portions of the project. However, more complete detailed coverage of the first phase of this project can be found in Technical Memorandum M-63-76-14 (Ref 1).

## BACKGROUND

DODX boxcars that carry ordnance of other explosive materials are readily suspected as a possible source of explosions. This is especially so when an actual explosion has occurred in a train laden with explosives. In order to determine the possible mechanisms by which explosions in boxcars could be initiated, a survey of available information was made so that appropriate preventive measures could be taken. Those items pertinent to DODX boxcar safety are discussed below.

### Handling of Ordnance for Rail Shipment

Ordnance is normally loaded on pallets to a nominal height of 4 feet above the boxcar floor. Once the cargo loading is complete, the car is locked and not reopened until it reaches its destination. This type of cargo is relatively inert, that is, no fuzes or detonators are installed in them. The explosives used for ordnance are insensitive to vibration and atmospheric temperature extremes. Friction heating due to load shifting does not produce enough energy to cause detonations (Ref 1). The remaining possibilities of detonation of explosive material in locked boxcars are (a) prolonged exposure to high temperatures or (b) engulfment in fires (to cookoff). These possibilities are discussed in the following sections.

### Maximum Possible Temperature Inside a DODX Boxcar

Maximum temperatures inside a boxcar may occur when it is closed and stationary while exposed to a hot desert sun. Such measurements were made by the Naval Weapons Center (NWC) at China Lake, California; Figure 1 summarizes these data (Ref 1). As can be seen, these temperatures are relatively mild compared to the temperature extremes of 71C (160F) given in MIL-STD-810 for critical military items. It should also be noted that during shipment, because of the mixing and cooling effects resulting from car motions, the maximum temperatures achievable are expected to be lower than those given in Figure 1. Therefore, spontaneous ignition of the wooden boxcar interior due to hot weather, with the resulting detonation of the ordnance inside it, is highly unlikely.

### Initiation of a Fire

The combustible materials used in boxcars are the wood floor and side interior walls and the foam ceiling. Under the atmospheric temperature extremes described above, spontaneous ignition of these materials is not possible. For example, the threshold ignition temperature and heat flux for wood are in the neighborhood of 300C and 0.4 cal/sq cm-s, respectively (Ref 2); the foams used are generally classified as either self-extinguishing or nonflammable by some test standards. Therefore, any fire involvement in a closed boxcar with no ignition source inside must originate from the outside.

Train wheels become heated whenever a brake is used. For example, during a long downgrade, the temperature of the rim of a train wheel can be as high as 260C because of excessive braking. If a brake sticks (brake shoe fails to disengage), friction heating can cause the wheel to become red hot. Under such a situation, the radiative heat flux at the underside of the car floor nearest the wheel may be as high as 2.5 cal/sq cm-s (Ref 4 and 5), which is well above the threshold ignition heat flux (0.4 cal/sq cm-s). Using a muffle furnace, it was demonstrated that a boxcar floor could be burned through and finally cause a total fire involvement inside the boxcar (Ref 1). The whole process is relatively slow. The time required to burn through the boxcar floor may be 1 to 2 hours, and the total time required from the start of irradiation to total fire involvement inside the boxcar may be as much as 3 hours. It is interesting to note that there can be a sizeable fire inside the boxcar without anything visibly apparent from the outside.

### Need for an Early Warning System

It is concluded in Reference 1 that a stuck brakeshoe is by far the most likely overheating condition that could lead to total fire involvement inside a boxcar. However, sufficient time is available to allow for an early warning system to signal the train operators to take the necessary actions. Therefore, an early warning heat detection system is required to monitor the train wheel temperatures. The following discussions give the details and results of the development of such a system.



## WARNING SYSTEM

### Concept

The actual alarm system will consist of a detection function, a signal transmission function, a receiving function, and an alarming function. The overall system will be packaged into two units, as depicted in Figure 2.

The heat sensor is essentially a switch to turn on the power for the transmitter. When an overheated condition is sensed, this switch will close the internal battery circuit to the transmitter, which will then transmit a coded identification signal. The heat sensor activation temperature was selected as 100C. At this temperature, there is a minimum of 200C further temperature rise before ignition of the wood can occur. Since the fire development considered here is a slow process, an ample safety factor is provided, and the detector reaction time is not critical. A bimetallic disc-type limit switch located on the bottom surface of the car floor directly above the train wheel was recommended as the optimum detector and location. A cross section of the heat sensor is shown in Figure 3. Since each wheel of the boxcar has an equal probability of becoming overheated, a sensor is required for each.

The alarm signal, once activated, must be transmitted to the train operators for appropriate action. Since there is no source of electrical power on a railroad boxcar, the signal must be transmitted by either wire or radio waves. After considering the logistics problems involved in using wires between boxcars, this approach was abandoned, and a battery-powered radio transmitter was selected as the signal transmitting mechanism. The boxcar portion of the alarm system concept takes the form shown in Figure 4. Each boxcar in the train carrying explosives would be outfitted in this manner to implement the concept.

There would be only one receiving system required, and it should be located in the train caboose. The receiver need not be battery powered since there is a 12-volt power supply in the caboose; however, if 120 VAC is required then an inverter (12 VDC to 120 VAC) will be necessary.

The receiver and transmitter are to be installed and removed easily. It is expected that the transmitter will be removed when the boxcar is not in use, and it will not be reinstalled until the boxcar is again placed into service. However, the sensors, wiring harness, and transmitter mounting plate must be considered a permanent part of the boxcar once installed.

From an operational point of view, it is necessary for the individual transmitters not only to signal the alarm but to identify the boxcar affected so that appropriate action can be taken. The receiver must have an audible alarm as well as an alarm source identification display (preferably digital).



## Requirements

Based on the above discussions and the constraints imposed by boxcar design, the following requirements were developed:

1. Each boxcar must have an individual alarm system.
2. The sensors for the system should be located as near the wheels as convenient. Since the probability of having a stuck brakeshoe is the same for all wheels, it is reasonable to have one sensor for each train wheel.
3. The system must be self-sufficient, because electric power is not available on boxcars. To conserve energy, the power source must supply energy to the alarm system only when an overheating condition is detected. That is, the system must be activated only by the detector.
4. Transmission of signal by light or sound is impractical because the train may be very long and the noise level is generally high. Alarm signal transmission by radio waves is considered the best method, but this signal must not interfere with the local communication radio waves.
5. To permit fast and positive identification of the car in trouble, a digital alarm signal that represents the car serial number is most desirable.
6. The installation of the system must be simple, and it must not affect train operations.
7. The system must be reasonably priced and easy to maintain.
8. The system construction must be able to withstand the severe climatic extremes, shock and vibration typical of railroad boxcars. These environmental requirements and some performance requirements have been identified as follows (see Appendix):

- (1) Temperature range: -30C to 65C
- (2) Shock Impulse: Net change in velocity must be less than 10 mph
- (3) Vibration: Natural frequency of vibration,  $f_n > 14$  Hz
- (4) Moisture-proof packaging
- (5) Simple transmitter installation and removal
- (6) Transmitter press-to-test capability
- (7) Absolute minimum false alarm rate
- (8) Minimum 10-mile radius for alarm signal
- (9) Five-minute repetition of alarm, once initiated (in the event the train is passing through a tunnel when the alarm is initiated)

### Detailed Description

In order to implement the alarm system concept, commercially available equipment was modified and used throughout when possible. In this manner, costs were kept to a minimum, and the concept could be proven expeditiously. Commercially available alarm system hardware was found that met most of the system requirements. The transmit and receive frequency for system development and design was chosen as 160.22 MHz, which is within the FCC allocation band for commercial railroad operation. This frequency is between two normal frequency allocations. In an actual system the assigned frequency for the railroad involved would be chosen.

Heat Sensors. The heat sensors selected are manufactured by Elmwood Sensors, Inc., and are designated Model 3100. These are sealed, snap-action thermostats designed to close at  $100^{\circ}\text{C} \pm 10\%$ ; they are guaranteed from  $-65^{\circ}\text{F}$  to  $550^{\circ}\text{F}$  ( $-55^{\circ}\text{C}$  to  $285^{\circ}\text{C}$ ). The sensors are preset, weatherproof, and tamperproof, with normally open contacts. The expected life of each unit is 100,000 cycles.

Alarm Transmitter. The Motorola AR-81 Alarm Reporter was selected as the transmitter to be used in the heat alarm system. This transmitter (Figure 5) is designed to report the activation of contact closures (alarms) at remote locations via tone-coded FM radio transmission. The transmitter operates with a minimum of two alarm sensor contacts and can accommodate up to six if desired. Upon the activation of one or more of these contacts, the alarm reporter automatically transmits a preprogrammed sequence of tones. This tone sequence identifies the reporting station and status of each of the monitored contacts at the time of transmission.

The tone sequence is retransmitted five times at approximately 65-second intervals, with the first transmission occurring about 5 seconds after contact closure. At the end of this sequence, the equipment (alarm reporter) reverts to the monitoring state. Should additional contact closures occur during the initial program of five transmissions, additional tone transmissions will be broadcast such that there are always five transmissions following the latest alarm.

Each transmission consists of eight bursts of tones presented in an alternating sequence. Two tones are unique to the reporting site and serve as a two-digit address for that site. In addition, a "security" tone is simultaneously broadcast which protects the system against false display indications; it also permits sensor stations to selectively report to separate decoders using different security tones.

An alarm contact closure maintained for a minimum of 750 ms will activate the alarm transmitter. Power is then applied to the encoding circuits to initiate a 4.13-second delay so that the tone oscillators can stabilize. The transmitter is then "keyed," and only the security tone is transmitted for 1.3 seconds. The eight-tone burst sequence then begins; each burst lasts 0.340 second and is separated by 0.215-second intervals.

At the central station receiver, the decoded information is displayed (printed, if desired) approximately 1.5 seconds after receipt of the last tone. Thus, the response time of the alarm reporting system is approximately 12.0 seconds.

The transmitter performance specifications are:

Frequency: 160.22 MHz

Number of functions: two, expandable to six

Address capacity: 81 per security tone

Auxiliary functions:

test input initiates complete alarm transmission sequence

interrogate input provides single transmission tone sequence

reset input provides instantaneous program turn-off at any time

Alarm sensor input

requirements: Dry contact closure with 0.4 mA rating at 15 VDC. Closure to be maintained for at least 0.75 second; loop resistance less than 4,000 ohms

Alarm response time: 4.13 seconds after contact closure

Current drain: Monitor, 1 mA DC at 25C; 10 mA at 65C

Transmit, 3 amperes (12 watts radiated power)

Supply voltage: 16 VDC max; 10 VDC min

Weight: 35 pounds (including batteries)

Enclosure: JIC-type steel with stainless steel hardware, moisture-proof baked enamel

Size: 20 inches high x 12 inches wide x 5 inches deep

Battery Supply. Since there is no power source available on a railroad boxcar, each transmitter must be equipped with its own battery supply. The batteries selected to energize the alarm system are manufactured by Gates Energy Products and are designated as Product No. 0800-0027. Two 8-volt sealed packs must be connected in series to provide the desired 16 volts. These batteries are sealed lead-acid rechargeable units rated at 5 amp-hr.

The individual cells are sealed in a case to prevent acid, acid vapor, and electrolyte leakage. The cell can be operated during its normal life without loss of water even during continuous over-charge. The cell can be oriented in any direction in acceleration fields of several g's without alteration of its electrical characteristics, and it



may also be operated at elevated temperatures without failure. The shelf-life of the batteries is approximately 12 months, and the weight of the 16-volt pack is 7.4 pounds. The package size was chosen to be mounted inside the transmitter housing.

Alarm Display Receiver. The receiver and display unit selected for the heat alarm system is the Motorola AD-81 alarm display unit. This unit (Figure 6) provides the audible alarm for the train operator in addition to the digital boxcar identification display. The digital identification function is capable of providing individual sensor identification as well as boxcar identification if desired.\*

The receiver and the decoder are capable of providing up to 81 address displays if desired; however, additional display modules would be required. Thus, a single receiving system is capable of monitoring 81 boxcars. This capacity is considered sufficient for most trains transporting high explosives.

The coding scheme of this system requires the presence of a security (pilot) tone at all times during decoding. When this tone is combined with the very precise tones for alarm function and address, an extremely secure reporting system is formed. The transmission for each alarm report consists of the security tone and discrete tone bursts. This results in superior performance and reliable decoding even under severe noise conditions.

The receiver and display unit is intended to be mounted in the train caboose for use by the train conductor. This equipment requires 120-VAC, 60-Hertz power to operate; therefore, an inverter must be provided since only 12-VDC power is available in the caboose. The inverter selected to power this unit is a TRIPP-LITE, Model PV-200 FC, 12-VDC-to-115-VAC inverter rated at 200 watts.

There is a companion printer available from the manufacturer that can be plugged into the display unit to provide a hard copy of the alarms as they are decoded. This unit is not specifically recommended; however, train operators may prefer to purchase it for record purposes.

The receiver and display equipment must be shock-mounted inside the caboose with the same shock mounts used for the transmitters. Temperature and shock requirements in the caboose are not as great; however, the vibration problem will be the same.

Harness Hardware. The hardware to make up the harness was carefully chosen because of the environmental extremes to which the railroad boxcars are subjected. The signal wires had to be totally enclosed to protect them from flying rocks and moisture, and, in addition, the insulation had to be able to withstand temperatures over 100C (200F). In order to accomplish this, Teflon-coated No. 12 twisted pair conductors were used inside moisture-proof, flexible conduit. Each heat sensor was mounted inside a cast iron junction box with only the tip protruding as shown in Figure 7. In this manner, all wiring and connections are protected from the elements.

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\*This capability is above and beyond the heat alarm system requirements. Also, additional train monitoring, such as physical security, can readily be accommodated by this hardware.



The entire harness is mounted on the outside of the boxcar, and, once it is installed, it is considered a permanent part of the boxcar. The simplest method of installation is to tack-weld conduit straps to the metal skin of the boxcar when possible. When necessary, a stud gun can be used to attach the conduit straps to the wood underfloor. Figures 8 and 9 are photographs of a completed harness installation on a DODX boxcar.

## EVALUATION OF SYSTEM

Since the system is composed of off-the-shelf equipment that is modified as needed and assembled into the required system configuration, the evaluation of the system was primarily one of verifying the manufacturers' stated performance levels. Three transmitters, one receiver, and sufficient hardware to outfit three boxcars were purchased. Most of the hardware characteristics were verified in the laboratory; the remainder were verified by field tests.

### Laboratory Evaluation

The contact closure temperature for the heat sensor was measured in the laboratory by selecting random samples and subjecting them to a slowly rising temperature in an oven. All samples demonstrated the proper contact closure temperature within the manufacturers' specified tolerance of  $\pm 10\%$ .

The transmitter housings were modified so that the housing could be mounted with the long dimension vertical. This orientation allowed the batteries to be mounted at the bottom with all the electronics located above. The antenna had to be reoriented to the top instead of on the side. The antenna mounting hole on the side was plugged and sealed, and a new hole was drilled in the top. A watertight seal for the antenna mount was accomplished by using a rubber washer. The antennas purchased were one-quarter-wave flexible whip antennas (cut for 160.22 MHz), which were designed to provide an omnidirectional pattern when the top of the transmitter housing is mounted flush with the top of the boxcar. A mounting plate was fabricated for each transmitter, and the transmitter housing was attached to this plate by means of special shock mounts.

The transmitters were subjected to temperature extremes in the laboratory to verify the manufacturers' stated performance tolerances; they were found to be within specifications. The receiver and display units were connected to the inverter and a 12-volt battery to verify their operation. Since this equipment has been available commercially for some time, no operational problems were expected, and none were encountered.

### Field Evaluation

Arrangements were made to install the transmitter and harness on a DODX boxcar on a siding at the Naval Construction Battalion Center in Port Hueneme, California. This boxcar (Figure 10) is typical of the DODX

boxcars that have been used to make shipments of high explosives in the past. Upon close examination of the boxcar, it was found that there are several significant differences in its construction than those commercially used. (A commercial boxcar is shown in Figure 11.) The significant differences have to do with the floor-supporting framework and the truck assemblies. A close-up photograph of the commercial car truck assembly is shown in Figure 12, and a similar close-up of the DOD car truck assembly is shown in Figure 8. The differences in spring and bearing assemblies are readily apparent. The most significant difference in construction, however, is in the main frames of the boxcars. As shown in Figure 8, the DODX boxcar has a 3/8-inch-thick steel box channel member running the length of the car directly above the wheels. There was insufficient room to mount the heat sensors directly above the wheels and still maintain the recommended 4 inches of clearance. On the commercial car, the main frame channel structural members are not directly above the wheels, so this problem would not occur.

A common problem with both types of cars is the build-up of road grime on the underside of the cars, particularly in the vicinity of the wheels. This road grime must be cleaned off so that the sensor junction boxes can be mounted. On the DODX boxcars, the junction boxes were welded to the steel as shown in Figures 7 and 8. The build-up of road grime on the surface of the sensors as the car is used would eventually affect the sensitivity of the sensor. Therefore, a maintenance program of cleaning the sensors would have to be initiated. The road grime is simply a combination of oil and dirt which hardens with time. A simple periodic cleansing of the sensor's surface with a penetrating solvent will eliminate the problem. This could be done at the same time the journal bearings are lubricated.

The harness and transmitter were installed on the boxcar as shown in Figure 9. It was convenient to tack-weld the conduit braces to the metal skin of the boxcar. The harness and transmitter mounting plate, once installed, are considered to be permanent parts of the car and should be painted over to cover the bare metal exposed by the welds. As previously mentioned, the top of the transmitter box is located flush with the top of the boxcar. The metal roof of the boxcar then becomes a ground plane for the whip antenna, and the maximum, omnidirectional radiation from the antenna is effected.

The receiver was set up on a workbench in the laboratory with a rod antenna, while the transmitter was more than a mile away. Each sensor on the boxcar was heated, one at a time, to verify its internal connections, transmitter turn-on, and receiver activation. This test, which was coordinated by walkie-talkie communication equipment, indicated the system performance to be satisfactory.

The receiver and display unit was next installed in a vehicle so as to run on 12 VDC; the antenna was mounted on the top of the vehicle (which simulated caboose installation) to check the range of the transmitter. Again, the test was coordinated by walkie-talkie communication equipment. When the receiving vehicle traveled in a southeastern direction, a distance of 10 miles was reached (location E in Figure 13) before the receiver would not respond. In a northeastern direction, a distance of 7.8 miles (location C) was attained, and in a northern

direction, a distance of 6.8 miles (location A) was attained. In all cases some industrial buildings, freeways, and power lines were between the boxcar and the receiving vehicle. In all the tests, the distance of transmission was more than adequate.

Time and funding limitations did not permit locking the brake on one of the boxcar wheels and dragging the car until the sensor responded. While this might have been a desirable test to perform, it was unnecessary since the theoretical work was based on the results of this type of test. In addition, it would have been a destructive test for the particular wheel and brake assembly involved. The boxcar was connected several times to an engine to simulate the coupling and uncoupling normally associated with forming a train in the switchyard. No problems were encountered in this test; however, it was recognized that very severe shock impulses (greater than 10 mph free-standing impacts) probably do occur in practice and, therefore, a more sophisticated shock absorbing arrangement would be required.

## DISCUSSION

There are several organizations interested in early warning systems for use by train personnel. For example, the Naval Surface Weapons Center (NSWC), Silver Spring, Maryland, is developing a system to stop a train when a journal box becomes overheated. Amtrak is also developing a similar system. The primary concern of these investigations, however, is overheating of the journal box and possible subsequent derailment. These systems are, therefore, tied into the brake system and are designed to automatically stop the train, particularly passenger trains.

The approach taken in pursuing the heat alarm system for boxcars carrying explosives was somewhat different in that there was no attempt to make the system interfere automatically with the train operation. Indeed, rather than stop the train, the operators may wish to move the train, depending upon the circumstances when the alarm is received. Accordingly, the system is designed to provide early warning and boxcar identification only. The choice of actions to be taken upon receipt of the alarm signal is left entirely to the train operators.

## DODX Boxcar Assignment and Logistics

DODX railroad boxcars are maintained, serviced, and assigned to military installations for shipping purposes by the Military Traffic Management Command (MTMC), Ft. Belvoir, Virginia. The using military installations do not own the boxcars, but they do own some engines (usually diesel) for moving cars and assembling trains. The train, once assembled, is moved by a commercial railroad which provides the engine, the caboose, and the crew. DODX boxcars normally are returned to MTMC every 96 months for scheduled maintenance, or at other times if repairs are needed.



### DODX Versus Commercial Boxcars

MTMC has discontinued the use of DODX boxcars for hauling explosives and hazardous materials.\* There have been no shipments of such materials in DODX boxcars since roller bearing journals became mandatory on December 31, 1975. All shipments of these materials are now handled by commercial carriers.

It was noted earlier that the field evaluation of the alarm system disclosed some differences in construction between DODX boxcars and commercial boxcars, one of which was a longitudinal beam supporting the DODX boxcar shell directly over the wheels. This makes it necessary to relocate the heat sensors to less-than-optimum positions slightly fore and aft of the vertical centerlines of the wheels. On the commercial boxcar the support beams are not usually directly over the wheels, so relocation of the heat sensors would not be necessary.

### Alarm System Costs

The estimated costs of providing and maintaining the heat activated alarm system are summarized in Table 1. The initial and monthly costs for equipping one boxcar or a train having 30 boxcars carrying explosives and other hazardous heat-sensitive materials are shown. An 8-year service period was assumed for developing costs even though it is expected the electronic equipment will actually serve at least 10 years and the sensors and harness for an indefinite period. This service period was selected because it not only coincides with the 8-year economic life specified by the Naval Facilities Engineering Command (NAVFAC) in Reference 6 for ADP equipment, but also with the 96-month period for boxcar scheduled maintenance.

Although the data in Table 1 indicate an increase of approximately 50% in the cost of leasing over the cost of purchasing the alarm system components, there are advantages offered by leasing which should be considered.

(1) Leasing offers greater flexibility in equipping boxcars according to need, with possible savings in time and cost.

(2) Leasing facilitates changing the transmitter-receiver operating frequency in the event the boxcar is assigned to a different railroad with a different assigned frequency. The manufacturer of the alarm system is equipped and manned to do this much more easily, and probably at less cost to the DOD.

(3) Leasing facilitates maintenance of the alarm system. The lease arrangement includes maintenance by the manufacturer as shown under leasing in Table 1. These fees will be offset, at least partially, by savings in cost, time, and manpower to train DOD personnel to maintain the equipment.

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\* Telephone communications: Lt. Col. Rousseau, MTMC, October 1977.



(4) The leasing arrangement is actually a lease-purchase contract under which the DOD will own the alarm system components at the conclusion of the term (8 years or other length), with no additional payments.

#### Additional Uses for the Alarm System

DOD facilities that are considering the incorporation of the alarm system in their rail transportation equipment may want to consider additional possible applications that require only slight modifications. The channel capacity of the transmitters can be expanded from two to six by adding other types of switching or triggering sensors. The alarm equipment can be used to alert the train crew of attempts at theft, sabotage, or vandalism, or it can also monitor the railroad cars for smoke, excess vibration, derailment, or malperformance.

#### CONCLUSIONS

1. The intense heat from an overheated train wheel is the most probable cause of fire development inside a locked boxcar. Therefore, the best procedure for early warning of overheating in railroad boxcars is to monitor the temperatures of the wheels.
2. A heat-activated alarm system that uses existing technology and commercially available components has been developed, tested, and found to respond satisfactorily under simulated operating conditions. This system consists of two basic units: (a) a transmitter mounted on each boxcar that is activated by heat sensors monitoring each wheel, and (b) a receiver-display unit, which is carried in the caboose, that responds to and identifies the transmitter(s) on any boxcar(s) so equipped. Signal coding is incorporated to avoid false alarms.

#### RECOMMENDATIONS

1. It is recommended that the CEL-developed heat-activated alarm system be considered for incorporation in the proposed MTMC Safe Transport of Munitions (STROM) study, during which all prevention/detection/suppression techniques will be examined.
2. It is recommended that, if adopted, the alarm system components be leased rather than purchased, or if purchased that the manufacturers' maintenance services be procured.
3. It is recommended that the CEL-developed alarm system along with appropriate triggering devices be considered for other boxcar applications, such as physical security protection or malperformance indication.

#### ACKNOWLEDGMENTS

The assistance provided by Messrs. Gerald Duffy and Joseph Quigley of CEL in conducting these tests is gratefully acknowledged.

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Table 1. Alarm System Costs

(Based on 96-month boxcar maintenance period)

Component	Quantity	Purchase Price (\$)	Lease Price (\$)	
			Monthly	96-Month Total
One Boxcar System				
Two-function alarm transmitter	1	803.25	15.74	1,511.04
Sensors and harness	1	200.00	2.08 <sup>a</sup>	200.00
Receiver and display unit	1	1,252.90	24.56	2,357.76
Maintenance	per transmitter	480.00 <sup>b</sup>	5.00	480.00
Total		2,736.15	47.30	4,548.80
Operating cost <sup>c</sup> (\$/mi/mo)		0.01	—	0.02
System Costs for 30-Boxcar Train <sup>d</sup>				
Two-function alarm transmitter	30	24,097.50	472.20	45,331.20
Sensors and harness	30	6,000.00	62.40	6,000.00
Receiver and display unit	1	1,252.90	24.56	2,357.76
Maintenance	—	14,400.00	150.00	14,400.00
Total		45,750.40	709.16	68,088.96
Operating cost <sup>c</sup> (\$/mi/mo)		0.16	—	0.24

<sup>a</sup> Installed cost prorated over 96-month period.

<sup>b</sup> Alarm system component maintenance cost for purchased equipment assumed to be the same as that quoted by the manufacturer for leased equipment.

<sup>c</sup> Assumed average travel for boxcar: 3,000 miles per month.  
Cost rounded to nearest cent.

<sup>d</sup> Considering only boxcars carrying ordnance or explosive materials.



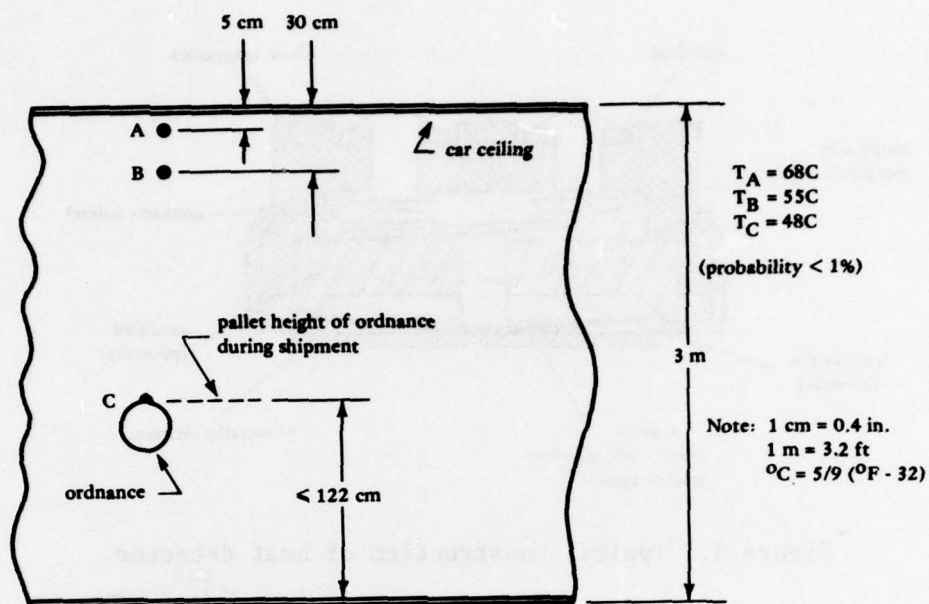


Figure 1. Maximum temperature inside a stationary boxcar loaded with ordnance.

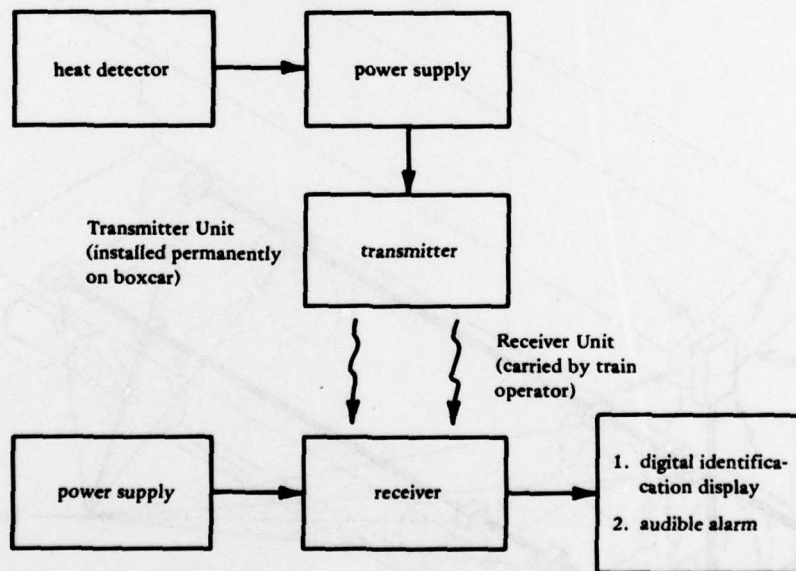


Figure 2. Schematic of a proposed heat alarm system for boxcars.



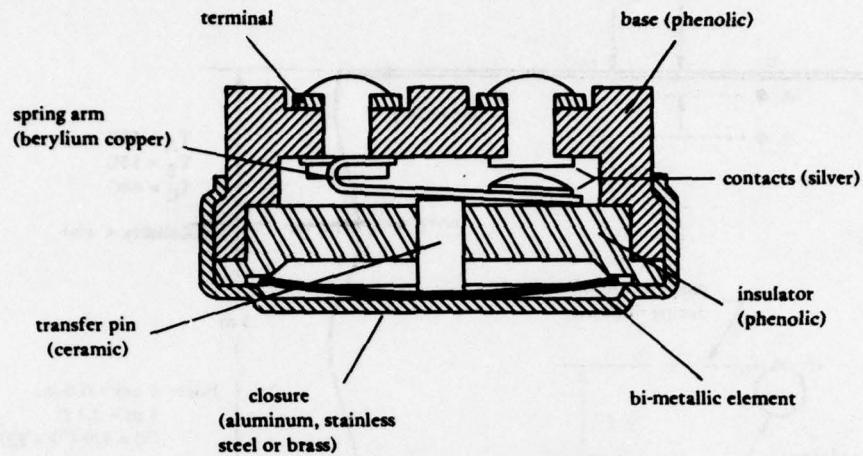


Figure 3. Typical construction of heat detector.

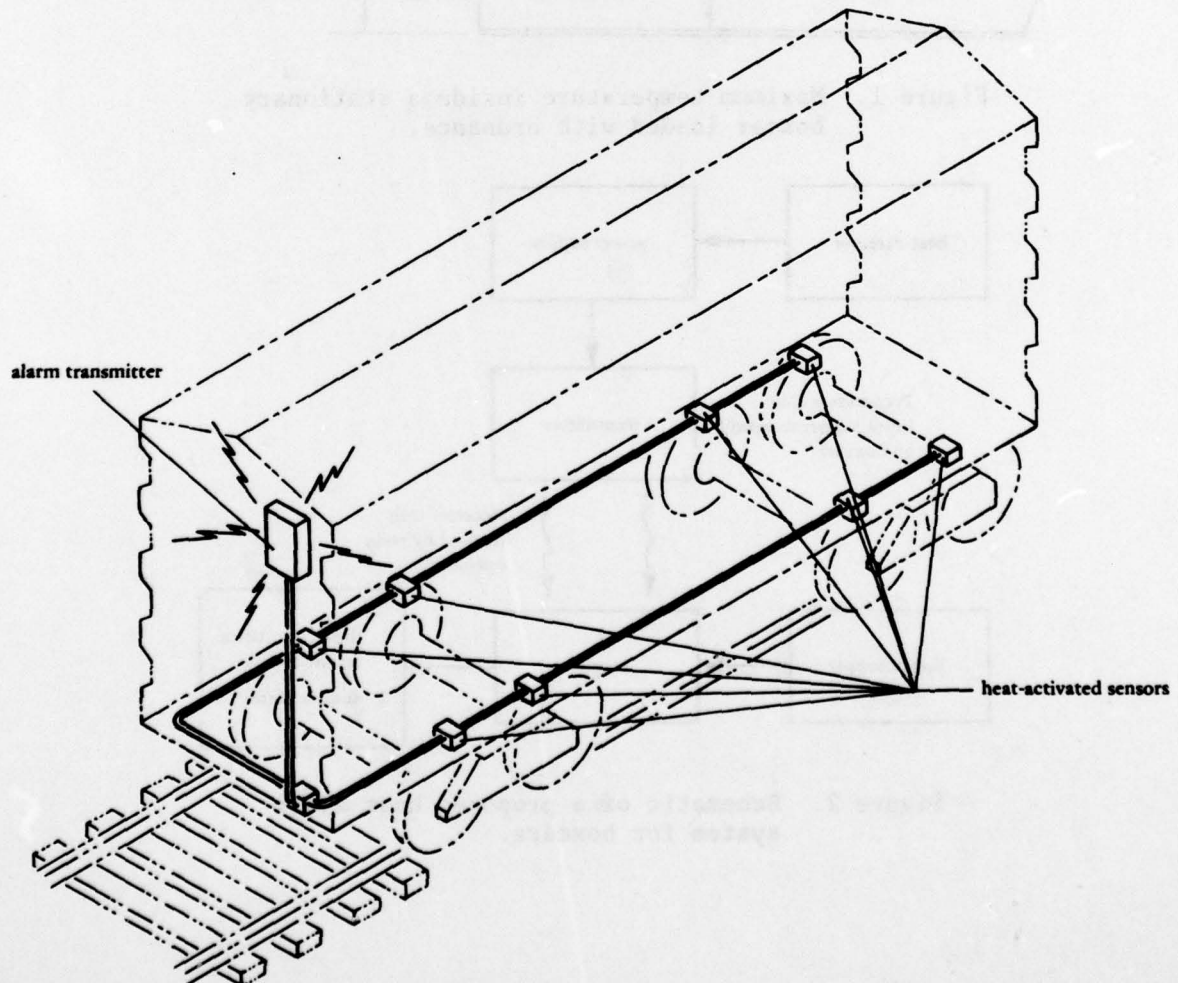


Figure 4. Heat-activated alarm system for boxcars carrying explosives.

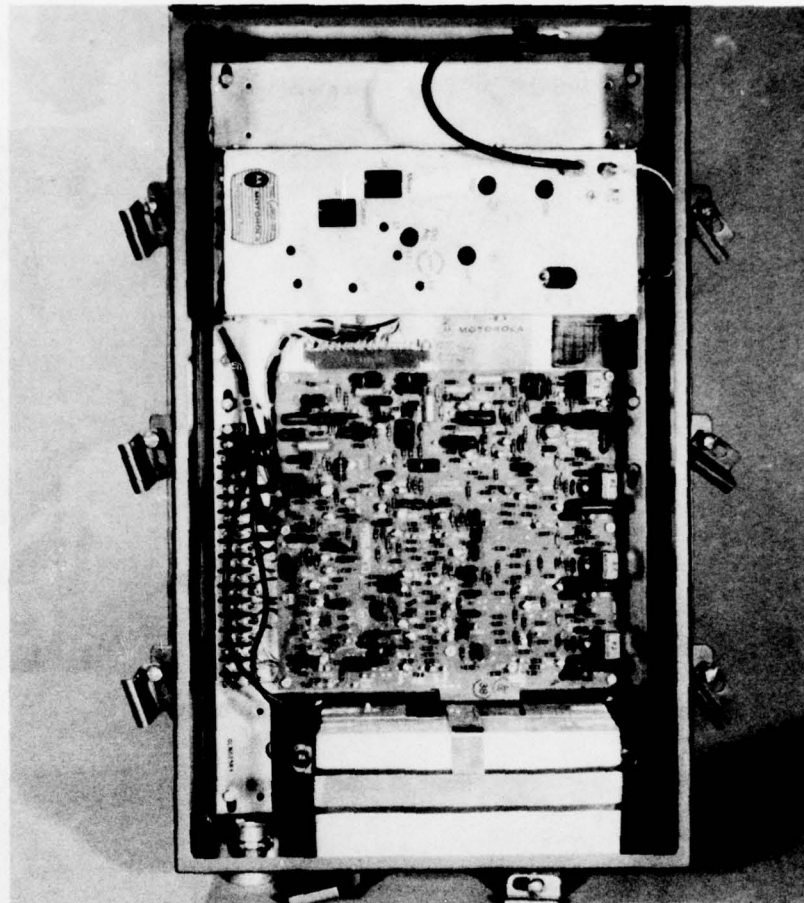


Figure 5. Motorola AR-81 alarm reporter (transmitter for heat alarm system).

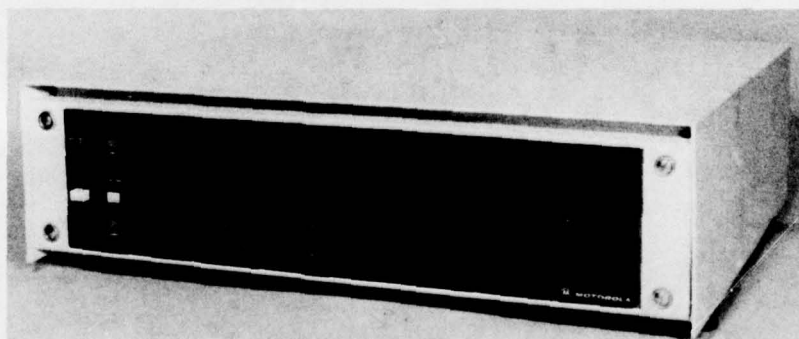


Figure 6. Motorola AD-81 alarm display unit (receiver for heat alarm system).

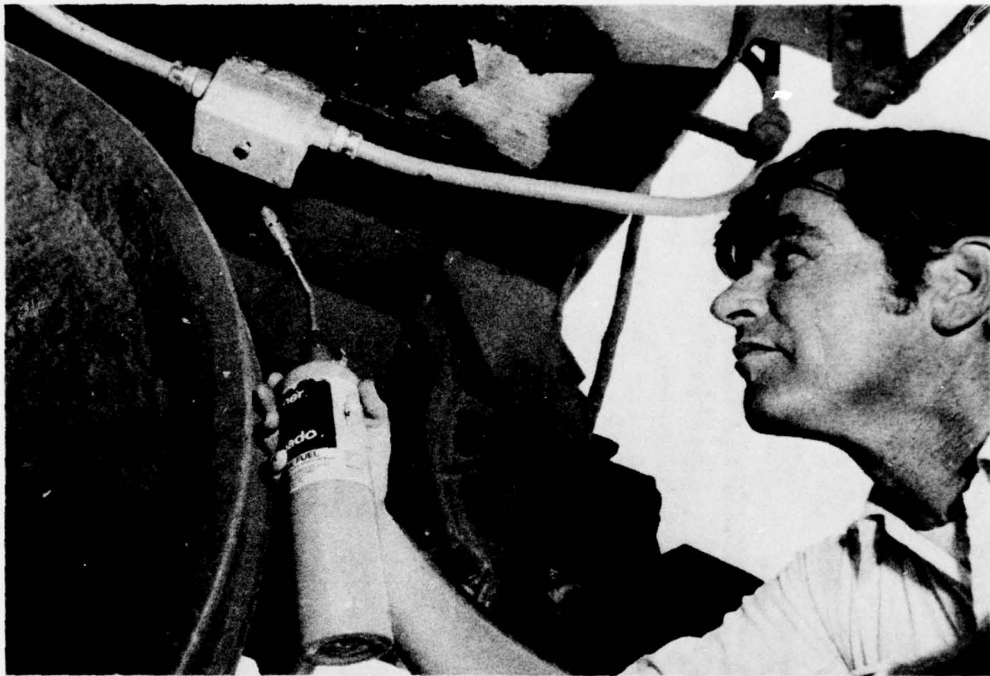


Figure 7. Heat sensor mounted on boxcar.

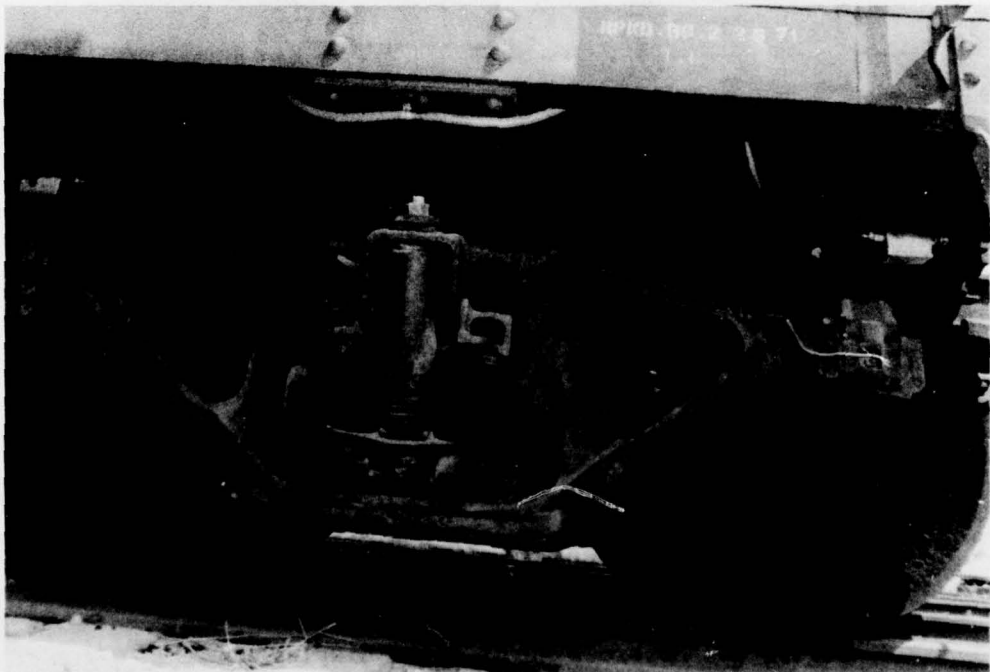


Figure 8. Harness installation beneath boxcar.



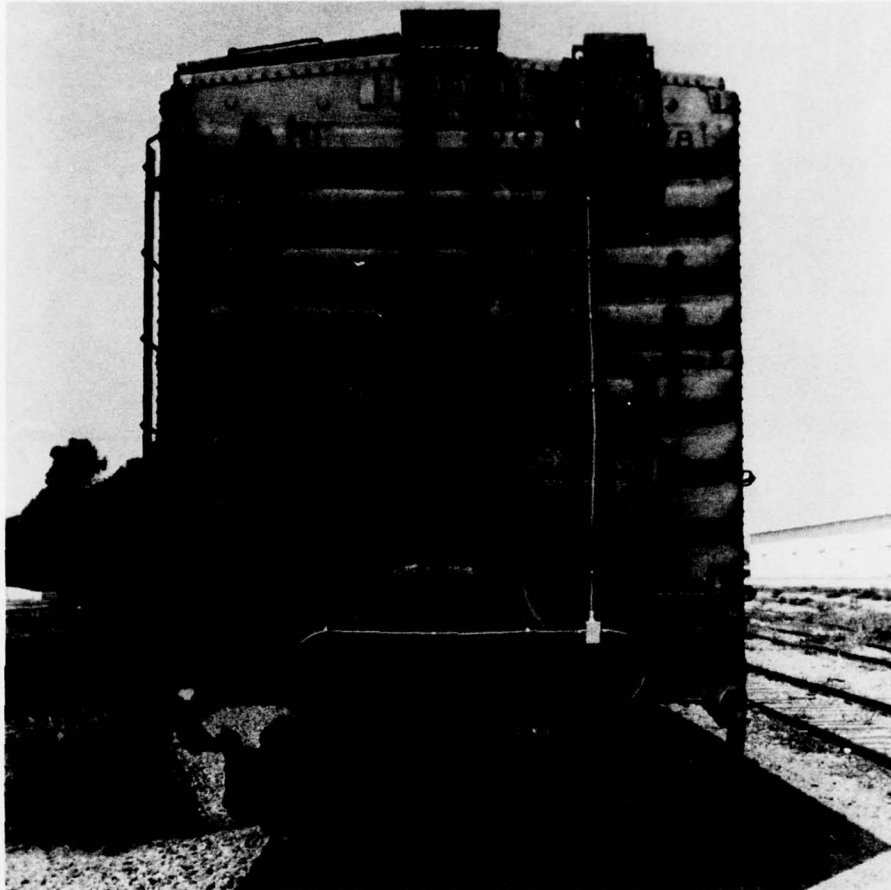


Figure 9. Harness installation on end of boxcar.

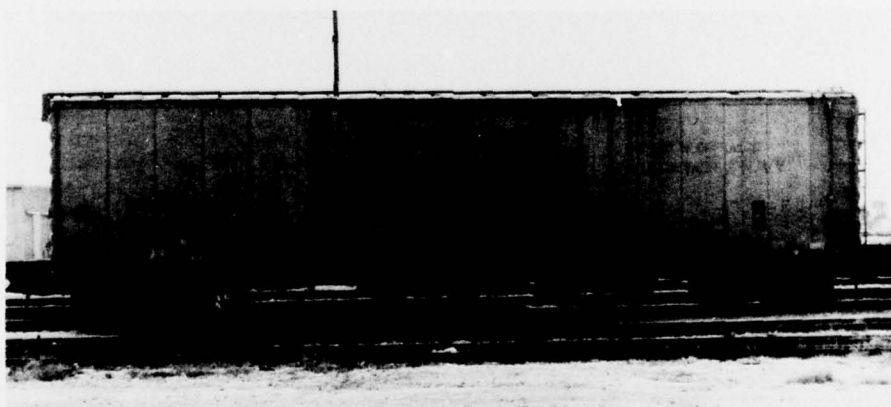


Figure 10. Typical DODX boxcar.

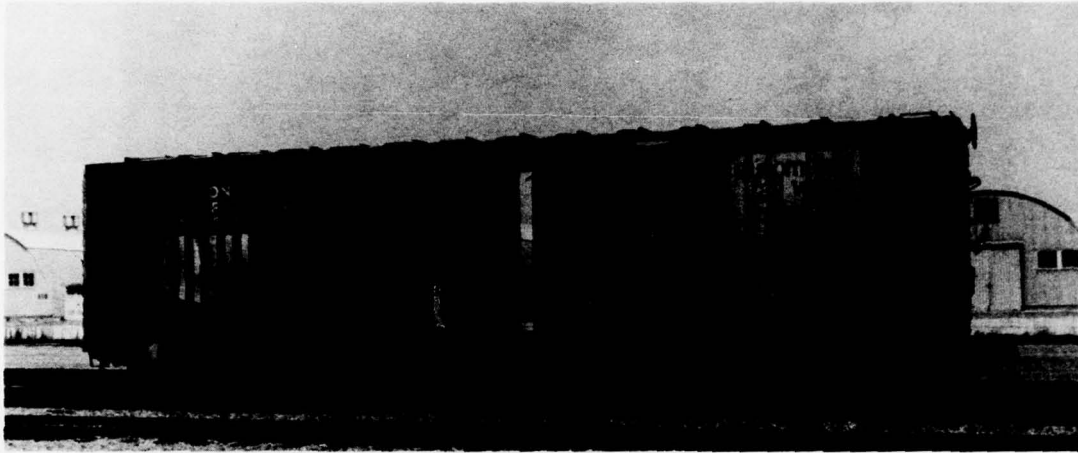


Figure 11. Typical commercial boxcar.

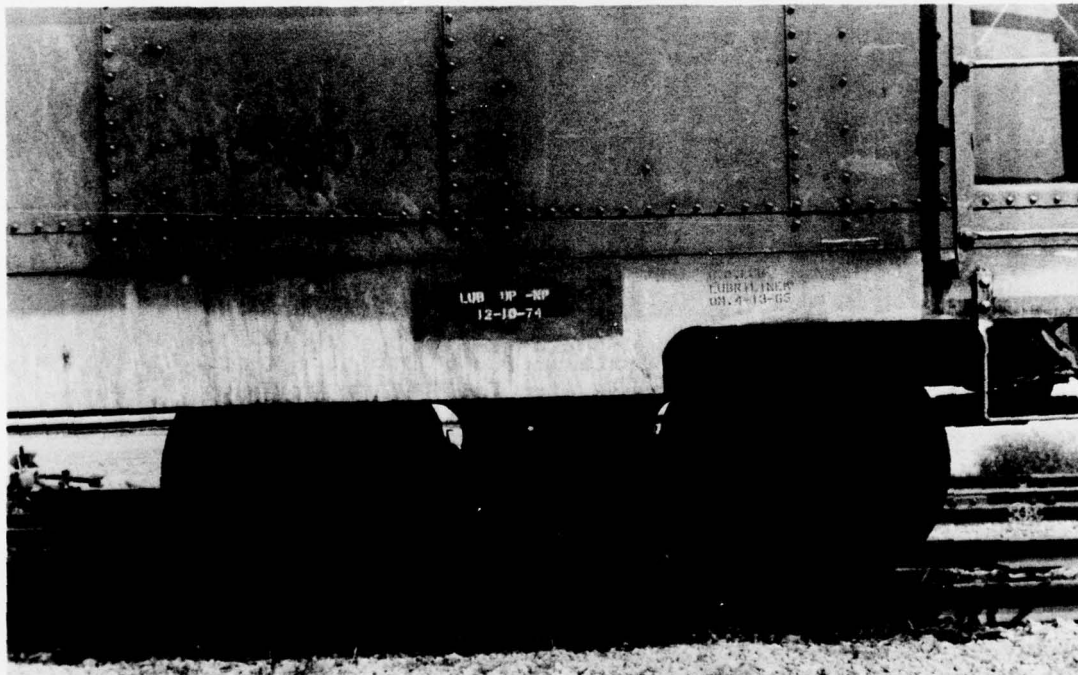


Figure 12. DODX car truck assembly.

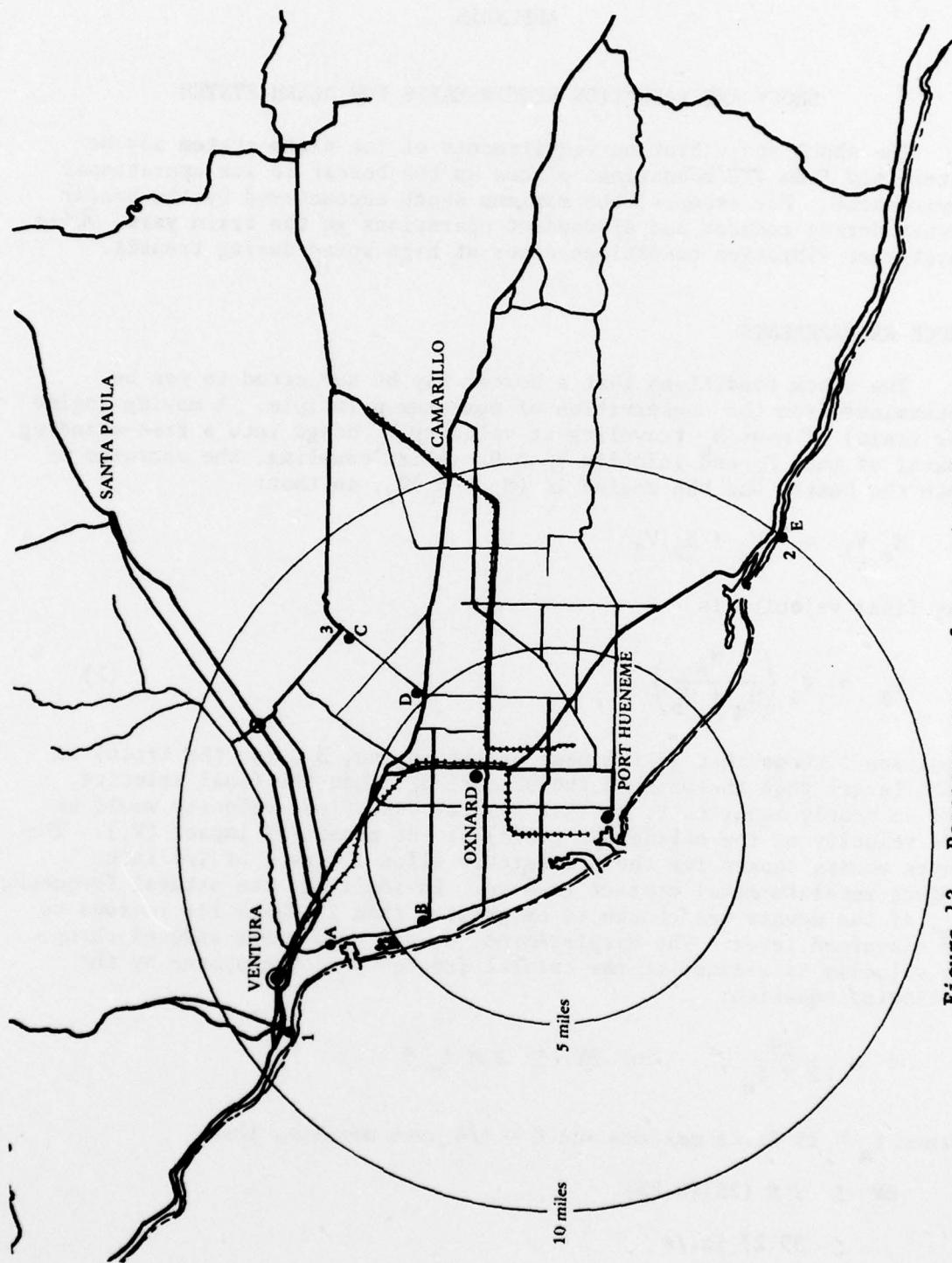


Figure 13. Response range of transmitter/receiver.



## APPENDIX

### SHOCK AND VIBRATION REQUIREMENTS FOR ALARM SYSTEM

The shock and vibration requirements of the alarm system may be determined from the conditions placed on the boxcar in its operational environment. For example, the maximum shock encountered by the boxcar occurs during connect and disconnect operations in the train yard, while worst-case vibration conditions occur at high speed during transit.

#### SHOCK REQUIREMENTS

The shock conditions that a boxcar may be subjected to can be determined from the conservation of momentum principle. A moving engine (or train) of mass  $M_e$  traveling at velocity  $V_1$  bangs into a free-standing boxcar of mass  $M_b$  and velocity  $V_b = 0$ . After coupling, the momentum of both the boxcar and the engine is  $(M_e + M_b)V_2$ , so that:

$$M_e V_1 = (M_e + M_b)V_2$$

The final velocity is

$$V_2 = V_1 \left( \frac{M_e}{M_e + M_b} \right) \quad (1)$$

Equation 1 shows that if the mass of the engine,  $M_e$ , (or the train) is much larger than the mass of the boxcar,  $M_b$ , then the final velocity,  $V_2$ , is nearly equal to  $V_1$  so that a worst-case final velocity would be the velocity of the engine (or train) at the moment of impact ( $V_1$ ). The shock mounts chosen for the transmitter allow a travel of 1/4 inch before metal-to-metal contact is made. In addition, the natural frequency,  $f_n$ , of the mounts was chosen to be greater than 25 Hertz for reasons to be discussed later. The displacement,  $d$ , due to a shock-induced change in velocity is related to the natural frequency of the system by the following equation:

$$d = \frac{\Delta V}{2 \pi f_n}, \quad \text{or} \quad \Delta V \leq 2 \pi f_n d$$

Since  $f_n = 25$  Hertz maximum and  $d = 1/4$  inch maximum, then

$$\begin{aligned} \Delta V &\leq 2 \pi (25)(0.25) \\ &\leq 39.27 \text{ in./s} \\ &\leq 2.23 \text{ mph} \end{aligned}$$

In order to withstand a 10 mph impact, a series of four shock mounts is necessary. In practical terms, this means that the train engine velocity at the moment of coupling should not exceed 2.2 mph. In the event this speed is considered too slow by the train crew, more expensive shock mounts must be used or the alarm transmitters must be installed only after the train is completely formed.

#### VIBRATION REQUIREMENTS

The worst case that can occur as far as vibration is concerned is when one of the wheels of the boxcar is slightly out of round or there is an imperfection in the circumference of the wheel such that a bump occurs every revolution of the wheel. In this event, a vibration of the car will occur, the frequency of which is directly related to the velocity of the car. If this forced vibration should happen to coincide with the natural frequency of the shock-mounted transmitter, excess vertical travel of the transmitter package will occur, resulting in damage to the transmitter.

For a practical look at the situation, if a 33-inch-diameter boxcar wheel has a circumference of 103.57 inches, a forced vertical deflection will occur every 103.57 inches of horizontal travel. For example, at 10 mph, which corresponds to 176 in./s, a forced vertical deflection will occur every 0.588 second. The following table shows the frequency of forced vibration corresponding to practical values of train velocity.

<u>Train Velocity (mph)</u>	<u>Frequency of Forced Vibration (Hz)</u>
5	0.849
10	1.699
20	3.398
30	5.097
40	6.796
50	8.495
60	10.194
70	11.893
80	13.592

From this table the maximum forced-vibration frequency is less than 14 Hertz. Therefore, the natural frequency of the shock-mounted transmitter package must be greater than 14 Hertz.

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